Crustal Deformation and Source Models of the Yellowstone Volcanic Field from Geodetic Data

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RESEARCH OBJECTIVES

The Yellowstone volcanic system is tectonically active, driven by intraplate extension at the eastern edge of the Basin-Range Province. This region has experienced the largest historic earthquake in the Basin and Range province, the M7.5 1959 Hebgen Lake Event. The Yellowstone caldera is the vertex of multiple north- to northwest-trending normal faults, and at this time the extent to which these faults interact with and control the magmatic and hydrothermal system is not known. The rapidly varying and complex deformation of the Yellowstone caldera raises a number of questions: What process drives this deformation? What is the role of pressure change and mass flux? If there is significant mass flux, what is the ratio of partial melt, hydrothermal fluids, and/or gases? What factors control fluid fluxes and pressure changes in the subsurface—magma bodies, caldera structure, geologic boundaries, intersecting faults?

APPROACH

To gain insight into the factors controlling surface deformation, we construct models of subsurface volume change that are compatible with surface deformation data. Our approach, based upon the inversion of multiple types of geodetic data (including interferometric synthetic aperture radar [InSAR—Figure 1a]), is exploratory in nature. That is, we allow for an arbitrary, three-dimensional distribution of subsurface volume change. The resulting pattern of subsurface volume change and source geometry can provide clues to the factors controlling observed surface deformation. With an improved understanding of the nature of the controlling features, we may then go on to construct more detailed and prescribed models for the sources of deformation.

ACCOMPLISHMENTS

The primary accomplishment is a model of subsurface volume change that may be interpreted in terms of subsurface fluid migration [Figure 1b]. The picture that emerges is of subsurface volume change that correlates with the resurgent domes, the Elephant Back fault zone, a north-trending fault zone related to the volcanic vents, and the extensive magma body beneath the caldera. These correlations suggests that such features control or at least influence deformation within the caldera, either as zones of mechanical weakness or as pathways for fluid flow, or both. There is evidence to support the role of both the Elephant Back fault zone and a north-trending central caldera fault zone in both internal deformation and fluid flow. We thus hypothesize that the observed surface deformation within and adjacent to the Yellowstone caldera results from the interaction of an underlying, large-scale, crystallizing magmatic system and zones of weakness associated with crustal faults. In particular, large-scale pressure and mass changes within the magma body are focused into faults that act as narrow conduits or pathways for flow. It is the focused flow and pressure changes that give rise to the observed surface deformation.

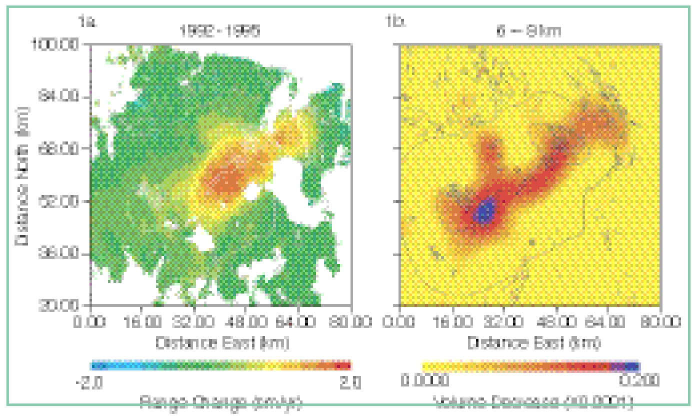

Figure 1a. Range change for the time interval 1992 to 1995. The color scale indicates the change in distance between the observation point in space and the surface of the Earth. Figure 1b. Volume change in the depth range is 6 to 8 km which is compatible with the observed range change.

SIGNIFICANCE OF FINDINGS

The findings are important because they further our understanding of how fluids interact with fault and fracture zones. Such interactions are critical to understanding hazards associated with volcanic regions and processes at work in geothermal fields. To date, little observational data are available on the interaction of fluids and faults/fractures in the earth. Most data are from idealized laboratory experiments or are interpreted using simple models. This work is the first step in an exploration of how geothermal fluids interact and influence faults and fracture zones. Understanding such interactions will help in finding new sources of geothermal energy.

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